1942 Vintage API-ASME Vessel Revitalization

Intersection of FEA, PCC-2, and NBIC

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Overview

- Background of 1942 vintage D-4 Debutanizer Tower
- Vessel history and desire to document design.
- Plan to determine structural integrity and restore the tower for another 12 years of service based on analysis and projected conservative corrosion rate.
- Use of NDE methods to map component thickness and areas of corrosion.
- Use of Finite Element Analysis (FEA) to document design and develop repair requirements
- Use of NBIC Part 3 External Weld Overlay to Repair Internal/External Corrosion with State approval.
- Code and other repairs completed to revitalize the tower

Background

The Problem

- Built in Berkeley, CA in1942, D-4 Debutanizer is 72 years old
- 1940 API-ASME Construction Code, A-70 CS, design stress 13.5 ksi carbon steel, no PWHT (SF=4, E=0.78), 8 ft. ø ~95 ft. tall
- Re-rated in 1957 using 1951 API-ASME Code; constructed pressure of 95 psi, an initial wall thickness of 0.625", a weld efficiency of 0.78, and a corrosion allowance of 0.0625". The currently rated operating pressure of the vessel is 125 psi.
- 1997 replaced top 10 feet of tower due to long-term corrosion.
- 2007 found corrosion under insulation (CUI) which required thickness mapping and ~ 90 square feet of external weld build-up.
- **2014 - Revitalize D-4 tower for another 12 years of operation.**

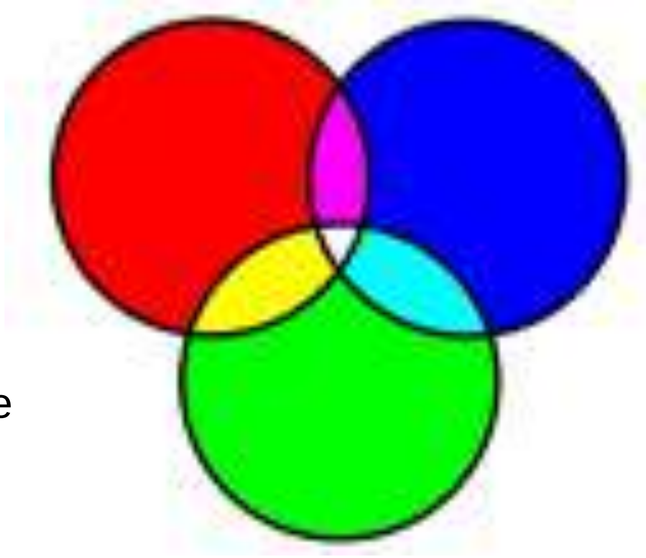
The Approach

- Complete vessel AUT scans & manual UT to map thickness
- Inspect the skirt for corrosion under fireproofing (CUF)
- Mechanical engineers and FEA analysis of D-4 shell and support skirt corrosion:
  - To understand structural integrity of the vessel and determine required weld repairs for 12-year life.
  - To upgrade resistance to seismic and wind loadings.

Overview of Approach To Achieve D-4 Revitalization Goals

NBIC

- O-U vessel inspection per Inspection Plan; review of vessel documentation and history
- R-symbol organization completes repairs per Repair Plan
- Part 3 External weld overlay 3.3.4.3-c, 3.3.4.3-e requirements evaluation
- O-U AI inspector used for repairs
- Qualified NDE procedures and qualifications for UT, AUT, UTSW, PT, RT reviewed



ASME PCC-2

- Design of external weld overlay (Article 2.2)
- R-symbol organization Repair Plan
- O-U AI for repairs review
- Jurisdiction approval of weld overlay Repair Plan per NBIC and ASME PCC-2, and NDE in-lieu of hydrotest

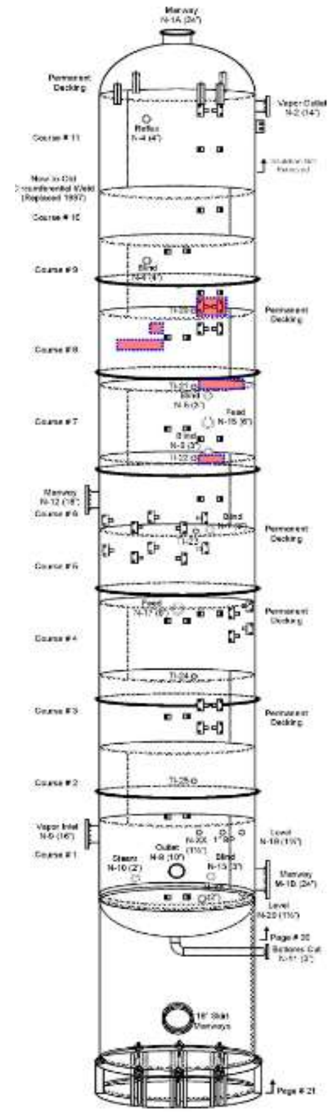
FEA

- FEA to supplement or justify the design of the API-ASME construction code re-rate, and check areas not adequately covered by the construction code.
- Use PE Pressure Vessel practitioners to recommend repairs based on FEA.
- O-U AI to verify the validity of the PE report. (refer to NBIC ballot)

NDE Mapping of Vessel Thickness

Ultrasonic Thickness Mapping and UT-grid

- Staged all around the tower ('ballroom'), removed insulation, and grit blasted the shell to remove scale and old paint.
- QualSpec completed automated UT (AUT) scanning doing 9.5 courses of the shell (excluded new top section replaced in 1997). API-QUTE industry-qualified UT shear wave examiner and a ASNT-TC-SC1 Level II shearwave qualified technician.
- QualSpec used manual UT for nozzles, manways, and locations where AUT was not possible (support clips, ladders, etc…)
- O-U inspector working with QualSpec AUT scan data created a 3-D layout with corrosion thickness bands for the shell sections.
  - Included lowest readings in the band and average thickness range in the band.
  - This data was the basis for the FEA model and areas where weld repair would be required.
  - Manual UT used to confirm lowest reading locations and mark them on the shell. Identified 4 weld repair areas, ~14 sq. ft of surface
- O-U inspector used an NDE crew to UT-grid the skirt corrosion which was similar to a 'moon crater' surface.
  - The lowest thickness found was used for the skirt FEA. The foundation, anchor chairs and anchor bolts were in good condition.



Internal and External Inspections

Complete external inspection of the vessel

- Staging allowed access to the external shell, skirt, foundation, attachments, nozzles, etc… for visual inspection and thickness gauging. O-U API 510/NB inspector
- Located original nameplate where API-ASME code said it should be hidden under insulation below lower manway.
- Ladder, platform, reboiler support clips inspected. Some required replacement.

Complete internal inspection of the vessel

- Internal inspection of the entire vessel completed. Extra attention on corrosion in downcomer sections of the tower.
- Top section was internally grit blasted & WFMT inspected for Wet H2S SCC damage mechanism. No indications.


Skirt Corrosion Under Fireproofing (CUF)


Skirt-to-head Attachment (1”-thick castellated design)

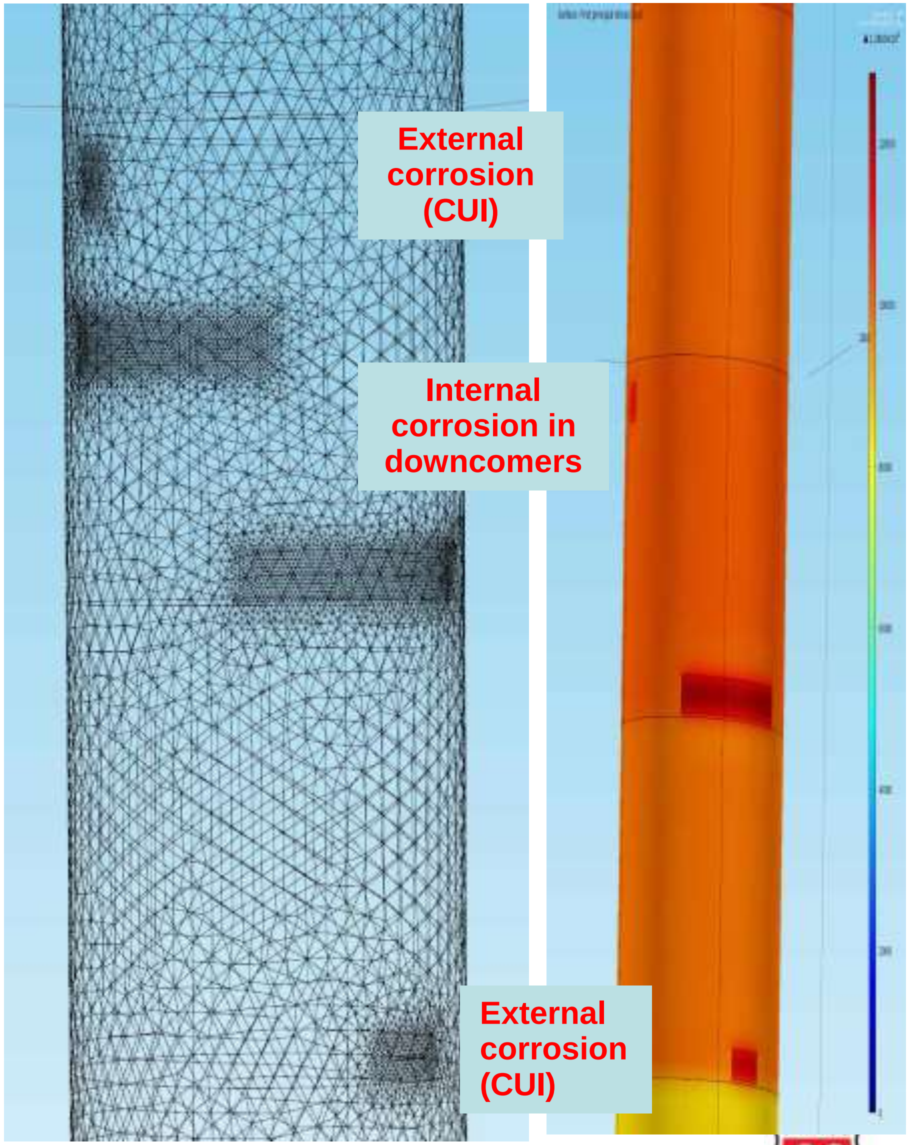

Internal Corrosion in Downcomer Area


Lower Shell and Ladder Support Clips

Finite Element Analysis of Shell

FEA for the Shell

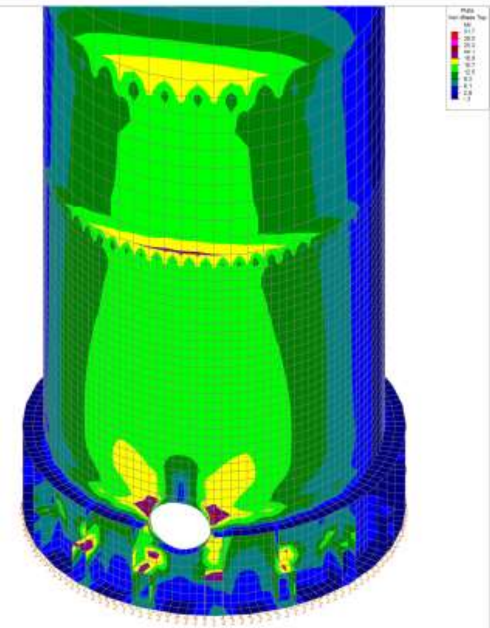
- BEAR (Berkeley Engineering and Research, Inc.) completed the shell FEA using the data from UT mapping and arranged by the O-U inspector.
- A 3D model was constructed of the vessel using shell elements and linear-elastic material model.
  - Excluded vessel connections, skirt and bottom head and assumed vessel attached at the base.
  - Included operating pressure, gravitational loads, and excluded negligible product fill in the vessel
  - Thickness assigned to each course was the minimum of the “average” thickness range for that course. For previous weld repair area “patches”, a patch in the model was created and the thickness assigned to the patch of elements was the minimum measured thickness in that patch, respectively.
- The model was subjected to the applicable loads and the resulting stress was determined.
  - The first principle stress was on the order of the design allowable stress for the thinnest sections of the vessel at the re-rate pressure.
  - The thinner sections were identified to be weld-repaired and brought to a higher thickness based on restoring to nominal thickness to satisfy future corrosion allowance.

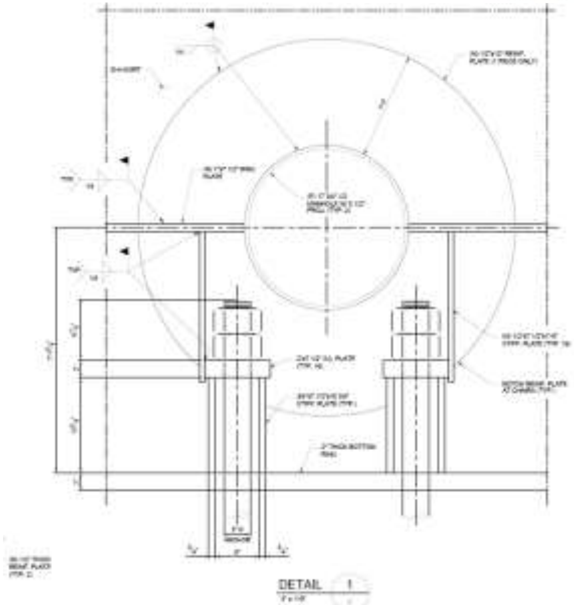


Finite Element Analysis of Support Skirt

FEA and Repairs for the Support Skirt

- ROBERTS Engineering completed the skirt FEA using the lowest thickness from UT-grids
- A 3D model of the entire stack, skirt, each anchor chair and skirt manways was created to induce seismic loads as realistically as possible in RISA3D.
- The current CBC2013 seismic code requirements were used.
- The model was used first to analyze the vessel in its current condition.
- The model was subsequently used to model the proposed modifications to return areas of maximum stress to their original stress state comparable to that of a new skirt condition.
- The modifications included adding a welded circumferential stiffening ring to the skirt with welded stiffener-plate ties between the ring and the anchor chairs, and manhole repads which were also attached to the stiffening ring.





Stiffener ring and manhole repad

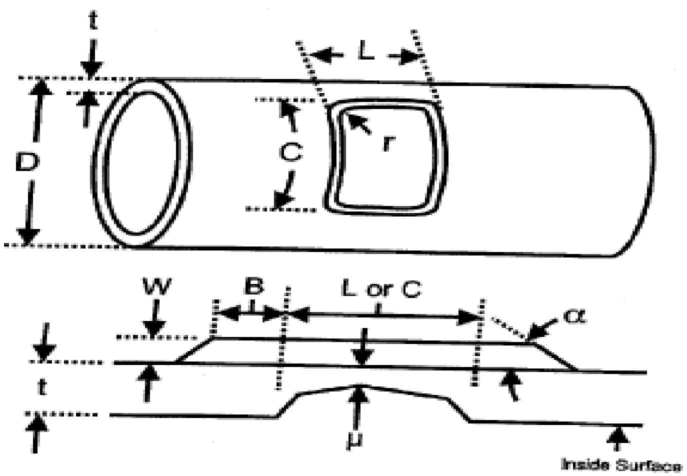
Stiffener plates to anchor chairs

Repairs to Thin Shell Areas

NBIC Repairs using External Weld Overlay

- Completed evaluation per NBIC Part 3 Section 3.3.4.3-e (items a thru m) and Figure 3.3.4.3-c (below)
- Brinderson, R-symbol stamp organization, completed code Repair Plan with weld procedure, and proposed NDE methods prior to welding and after welding completion with request to use NDE in-lieu of hydrostatic testing. Oversight by O-U AI of VT/PT/UT shearwave completed on all areas to be welded and included in request to the State.
- Leonard Tong, DOSH PV Unit, reviewed the package of information, made revisions with supplemental requirements for in-lieu of hydrotest, and approved the Repair Plan.

FIGURE 3.3.4.3-c
External Overlay Terms and Definitions



L = length of area to be repaired along the axis of the component
C = length of area to be repaired along outside circumference of the component
W = the completed thickness of the overlay
α = the angle between the component and the overlay (maximum 45°)
B = 3/4 $(R+t)^{0.5}$ minimum
R = nominal outside radius of the component
D = the nominal outside diameter of the component
t = nominal wall thickness of the component
μ = remaining wall thickness of the component shall be 1/16 or greater
r = minimum radius, not less than the overlay thickness

Completion of Repairs

- Brinderson completed the weld overlay within the allowed thickness, specified corner radii, and required taper at edges. Spots on the patches were 'flat-topped' with a flapper wheel to prepare for manual UT thickness checks of the overlay patches.
- O-U AI witnessed replacement of two platform vessel attachment clips (and associated platform).
- O-U AI completed VT and witnessed the PT of the weld overlay and UT spot thickness examinations to verify restoration of required thickness.
- Brinderson completed the skirt structural modifications (not code repairs but completed using a Repair Plan witnessed by the O-U AI and the Brinderson CWI)
- Brinderson and the O-U AI completed installation of the R-2 nameplate.
- Re-coated the tower and re-insulated the tower to prevent Corrosion Under Insulation.
- Replace the fireproofing on the skirt.